Fermilab

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Design Note about a 75 KVA Quiet Power Distribution System

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1. Subject

This note describes a 75KVA quiet power distribution system for X 653 in neutrino Lab D. It is fed from the regular AC distribution which exists in the building and it has no standby power. Its purpose is to remove electrical disturbances which are present on the regular AC distribution.

2. Quiet Power Need and Cost

The need for well regulated and clean AC power distribution in experimental area's increases when very sensitive electronic detectors are used by experimenters. It is difficult to define how much "noise" the detection equipment can withstand without giving erroneous results. Electrical noise levels will most likely change during the course of an experiment. A normal reaction is therefore to install the maximum amount of safeguards against noise. However quiet power distribution is expensive and should only be installed where needed.

The total material cost for this 75KVA quiet power distribution system is about $20.000. This is lot of money and it is therefore reasonable to ask the question: "Do we really need it?" I think that there is no easy answer, but it is certainly wise to design and install electronic equipment in such a manner that is is the least susceptible to noise. It is not economical to eliminate all noise completely and there will always be ground potential (noise) differences of several volts at different building locations.

It is probably true that many complaints attributed to AC noise, in existing installations, are the result of poor cable routing and equipment grounding techniques, instead of AC line disturbances. This could be especially true where distances between interconnected sensitive electronic equipment, grounded at various points along the way, are large. It is needles to say that clean AC power is only part of the solution. The whole installation should be installed, shielded and grounded properly, preferably at one point. This can be a problem since the national Electric Code (Fermilab) requires that all enclosures be grounded locally for personnel safety. Detectors should be designed with this requirement in mind. Routing sensitive cables away from noisy power cables and possibly shielding of equipment are good practices. These preventative measures have nothing to do with quiet AC power, but they can prevent a lot of problems. Once a system is installed it is very hard to find out where a problem comes from.

It is sometimes necessary to install a "cure" that should have made the noise worse. There is a certain amount of black magic involved with grounding, but no matter what happens, we must start off with well thought through logical approach.

3. Types of Electrical Noise

The following types of noise are generally present:

3.1 Common mode noise on the AC line.

Common mode noise exists equally on all wires of the AC distribution system and it is, as if the whole AC system floats up and down with respect to reference ground.

Common mode noise can be effectively reduced by a transformer with an electrostatic shield between the primary and secondary. Noise reduction of a factor of 500 is common.

3.2 Transverse noise on the AC line.

Transverse noise exists on the AC sine wave of the AC source. Examples are:commutation spikes, voltage dips etc. It travels easily through a shielded transformer, via the magnetic core. One way to clean up transverse noise is to install a line conditioner transformer. These non-harmonic output isolation transformers reduce transverse noise about a factor of 250. They also reduce common made noise about a factor of 2000 and regulate the AC output voltage.

Installation of power factor correcting capacitors reduces transverse noise even more and at the same time relieves expensive transformer capacity. Somewhat less expensive harmonic type line conditioning transformers will also reduce transverse noise substantially.

3.3 Ground noise and radiated noise.

Ground noise results from circulating currents running through the ground wires of a grounding grid system and earth. They are responsible for ground potential differences at various building locations, which are seemingly all connected together. Circulating ground currents can have many high frequency components on them. Not only the resistance but also the inductance of the ground system is important. Low inductance grounding of sensitive installations is important.

Ground potential differences on a building ground grid system of several hundred volt are possible during fault conditions and lightning storms. These voltages would normally be in the order of a few volts. Interconnected electronic equipment, which is spread apart in the building, must be designed to handle this type of "common mode" noise. The experimenters must police their installation to prevent the introduction of multiple grounds in their layout. Multiple grounds create another loop for ground currents to flow. These unintentional ground loops often go right to the input of an electronic detector, where they can easily confuse the wanted signal. It may be wise to run a heavy (low impedance) insulated ground wire along with the signal wires between interconnected electronic equipment, with the option of grounding either one end or both.

Radiated noise is the result from electromagnetic disturbances radiated from fluorescent lights, power cables, motors, soldering irons, walkie talkies etc. Proper shielding, low impedence grounding and avoiding ground loops are sensible defenses against this type of noise.

Only clean power should be used inside large shielded cavaties (shielded huts) and the use of incandescent lighting is better than flourescent. Heating, ventilation, airconditioning and cooling water should be ducted into the cavity from the outside via insulated sections so that these ducts do not act as "noise radiators" inside the shielded hut. The same is true for electrical power, where at least shielded isolation transformers should be used, at the point of power entry.

4. Lab D Quiet Power Distribution

Attached drawings ATV032784 Sh1, 2, 3, 4 show rather detailed information about the components and installation of the electrical parts. I am not in a position to say wether a less expensive solution would have worked also. It is true however, that the final scheme is less than what the original request was, because of the high cost. The experimenters requested two levels (SH3) of quiet power.

4.1 Quiet power via a shielded distribution transformer.

4.2 Extra quiet power via a shielded distribution transformer and a line conditioning transformer.

Studying the drawings we see that the ground loops around the sensitive area's are broken and that the relay racks have a "one point" low inductance ground connection, which should be used as the electronic equipment reference ground. Each relay rack is fed from its own line conditioner with power factor capacitor to eliminate cross talk between racks via the power lines. Each relay rack contains a small power distribution panel with outlets for internal power distribution. This is required because connecting 7.5KVA, via a splice box, to 30A and 15A receptacles in unacceptable. The experimenter has to make sure that the power distribution and grounds of the quiet system do not get mixed up with other equipment. The requirements for the shielded hut are the same as for the relay racks, in addition to the comments made under ground noise and radiated noise.

5. Equipment Cost

The following equipment costs (March, 84) are supplied for reference:

5.1 Transformer 75KVA 3 Phase 480/208V Electrostatic Shield	$1600
5.2 Transformer 7.5KVA Line Conditioner	$1900
5.3 Transformer 5 KVA Line Conditioner	$1550
5.4 Power Factor Corr. Cap. 25 KVAR 3 Phase 208V	$ 710
5.5 Power Factor Corr. Cap. 2.5 KVAR 1 Phase 208V	$ 170
5.6 Power Panel, 225A with Breakers	$1250
5.7 Power Distribution Panel For Relay Rack Complete with breakers and outlets	$ 100
5.8 1000 FT 3-Cond. #8 Cable	$1000
5.9 Total Equipment Cost for the 75KVA Quiet Power Distribution	$20.000

6. Closing Statment

The purpose of this memo is too make a user think about noise problems before he starts designing equipment. The problem is not new and a solution may be possible with commercially available equipment in addition too a proper design approach.

If this note has made the reader more aware of "noise and cost" then it was worth the time to write it.

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	EA	X653		1 OF 4

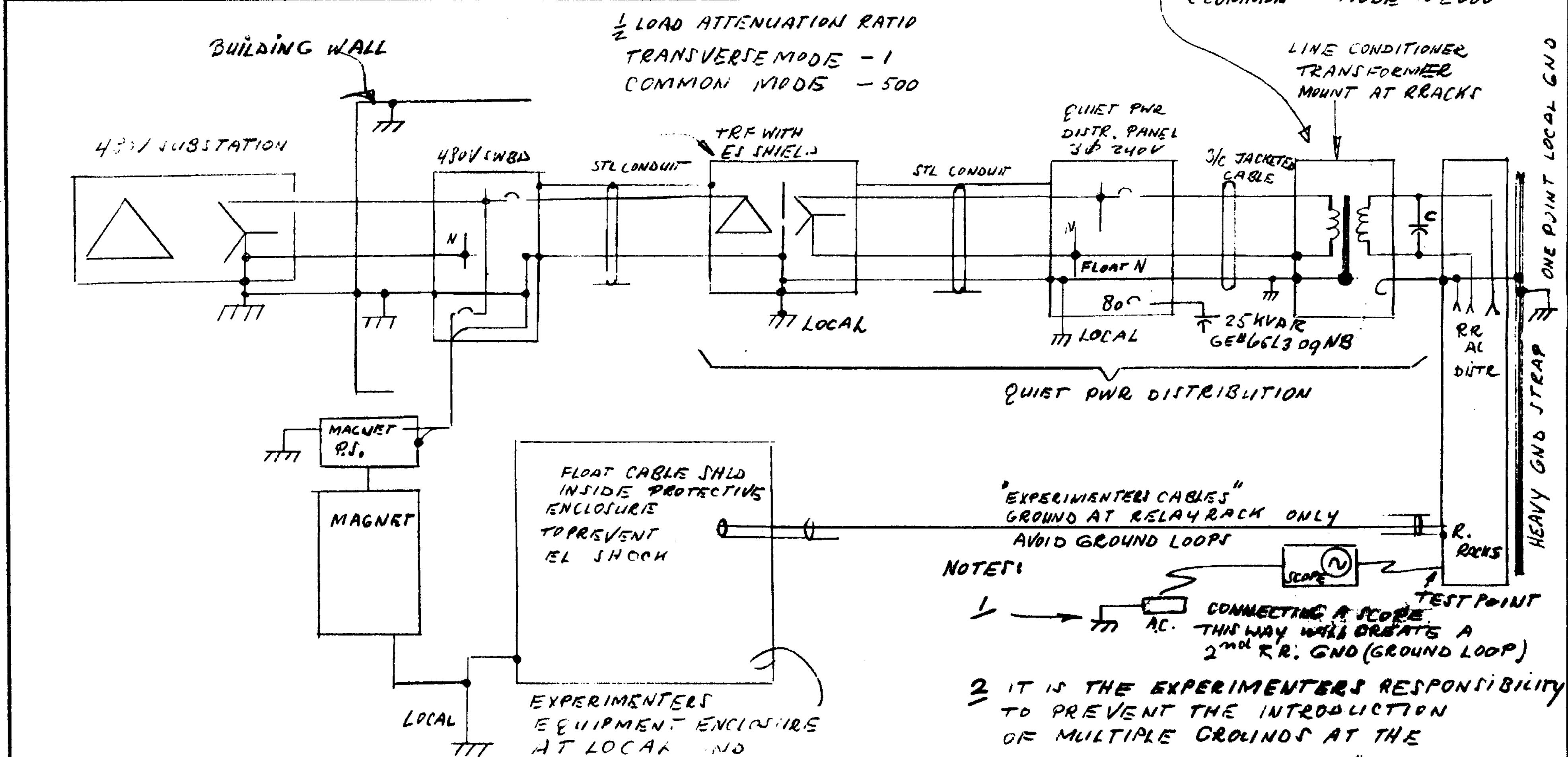
SUBJECT: EAD QUIET POWER DISTRIBUTION GENERAL PROPOSAL

NAME: A.T. VISSER

DATE: 3/14/84

REVISION DATE:

DRW # ATV 032784 SH 1



NOTES:

1 → CONNECTING A SCOPE THIS WAY WILL CREATE A 2^{nd} R.R. GND (GROUND LOOP)

2 IT IS THE EXPERIMENTERS RESPONSIBILITY TO PREVENT THE INTRODUCTION OF MULTIPLE GROUNDS AT THE RELAY RACKS VIA THE "EXPERIMENTERS CABLES."

3 $C = \frac{265 VA}{E^2}$ μF, VA = TRF VA
RECOMMENDED CAP. VA ~ 0.1 TRF VA

SH1

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EA	X653		2 OF 4

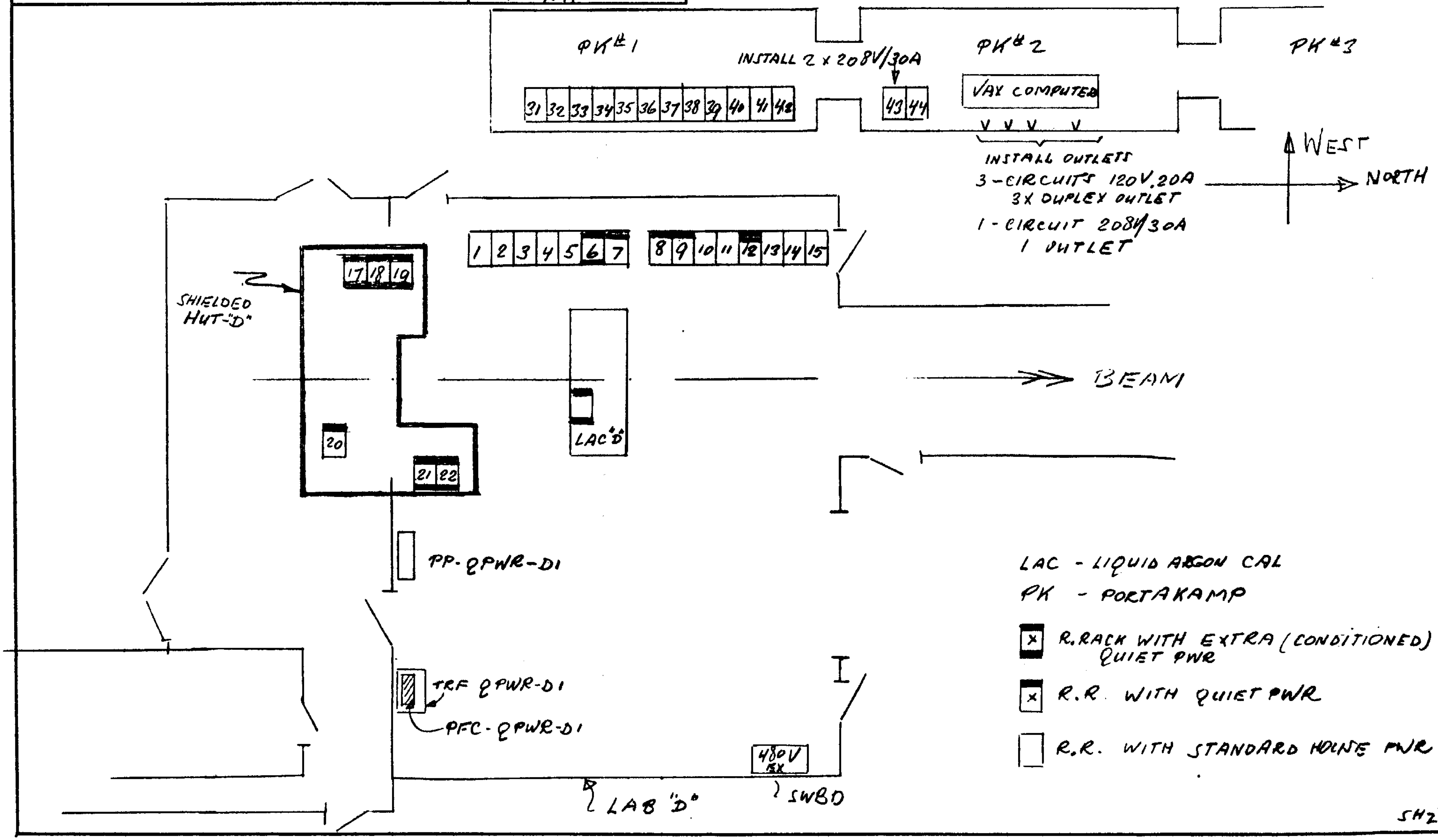
DRW # ATV032784 SH2

SUBJECT: QUIET PWR DISTRIBUTION PLAN NEUTRINO LAB "D"

NAME: A.T. VISSER

DATE: 3/26/84

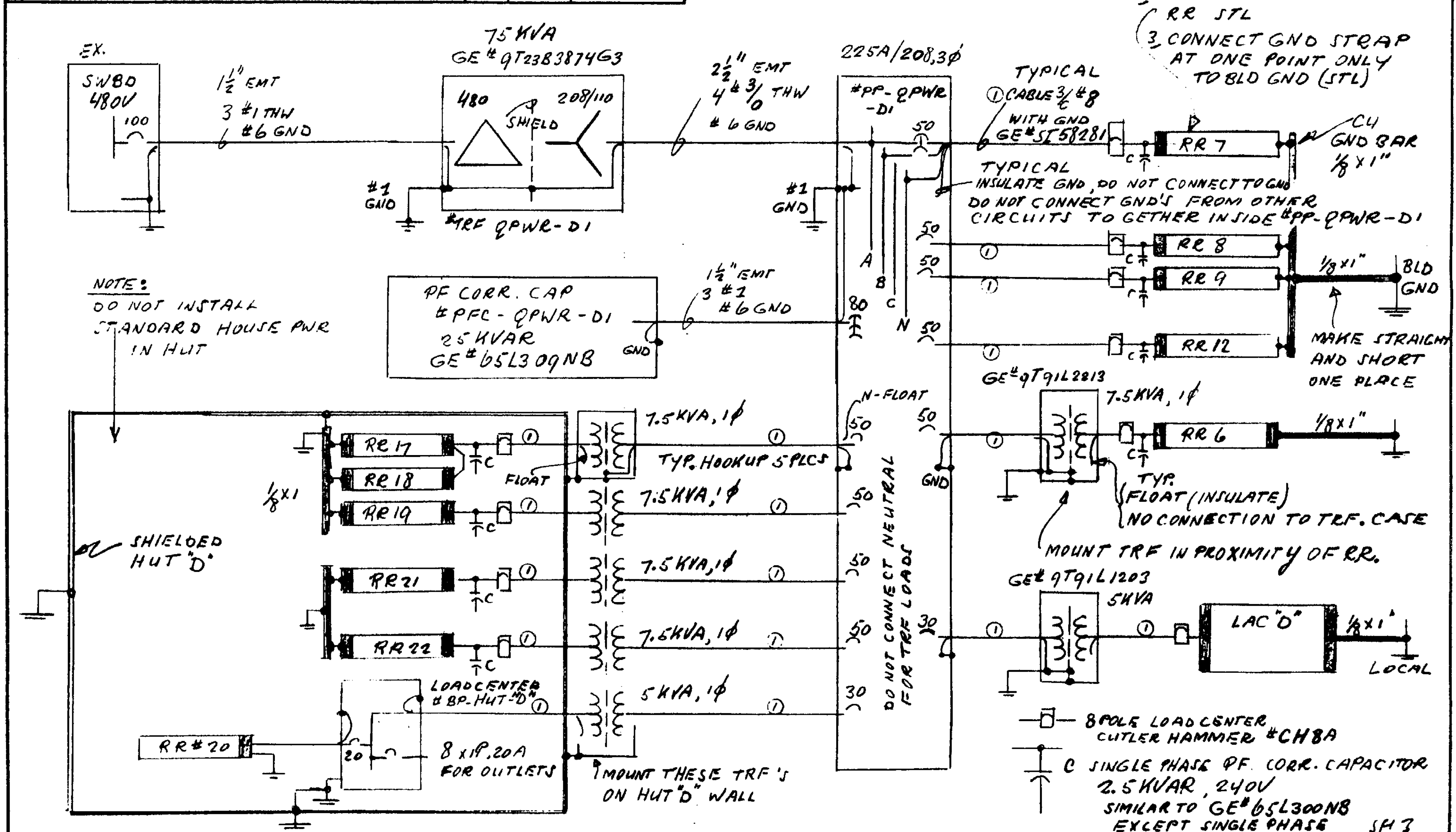
REVISION DATE:



FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	EA	X653		3 OF 4

SUBJECT	NAME	
QUIET PWR SINGLE LINE NEUTRINO LAB "D"	A.T. VISSER	
	DATE 3/27/84	REVISION DATE

DRW# ATV032784 SH3



FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EA	X653		4 OF 4

SUBJECT: QUIET POWER TYPICAL RELAY RACK, WIRING DETAILS

NAME: A.T. VISSER

DATE: 3/28/84

REVISION DATE:

DRW# ATV 032784 SH4